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MODIFIED SINGLE SURFACE TREATMENT USING STEEL SLAG AGGREGATE

MATERIALS INFORMATION
ENGINEERING MATERIALS OFFICE

MODIFIED SINGLE SURFACE TREATMENT USING STEEL SLAG AGGREGATE

by

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CONTENTS

	PAGE
ABSTRACT	iv
INTRODUCTION	1
BACKGROUND	1
Description of Previous Trial	2
Description of Modified Single Surface Treatment Trial	2
Trial Location	3
Control Trials	3
MATERIALS	
Aggregate	5
Asphalt Binder	7
Application Rates	7
CONSTRUCTION	8
Equipment	8
Procedure, Modified Single Surface Treatment	9
Procedure, Double Surface Treatment	13
Traffic Control	13
Rotary Power Brooming	13
COSTS	
Modified Single Surface Treatment	14
Double Surface Treatment	14
COST COMPARISON SURFACE TREATMENT VS. HOT MIX	14
COMPARISON OF PAVEMENT SURFACE CHARACTERISTICS	16
Skid Resistance	16
Sound Level	16
Texture Depth	18
PERFORMANCE	19
Comparing Performance of Modified Single Surface Treatment with Double Surface Treatment	20
Winter Maintenance	20
Safety	21
Comments from Property Owners	
CONCLUSIONS	21
RECOMMENDATIONS	22
ACKNOWLEDGEMENTS	22
APPENDIX A: Aggregate Grading and Physical Test Results	23

PAGE

APPENDIX B: Laboratory Procedure for Selecting the Most Suitable Type and Grade of Emulsified Asphalt for a Given Aggregate for Surface Treatment 25

APPENDIX C: Field Tests to Confirm Emulsion-Slag Compatibility 27

APPENDIX D: CRS-2 Laboratory Test Results 29

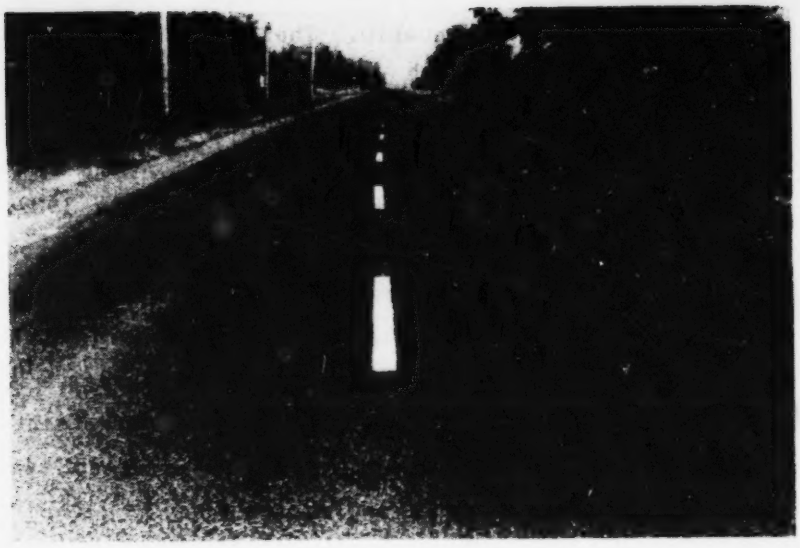
APPENDIX E: Field Sampling to Determine the Amount of Binder and Aggregate Applied to a Road 30

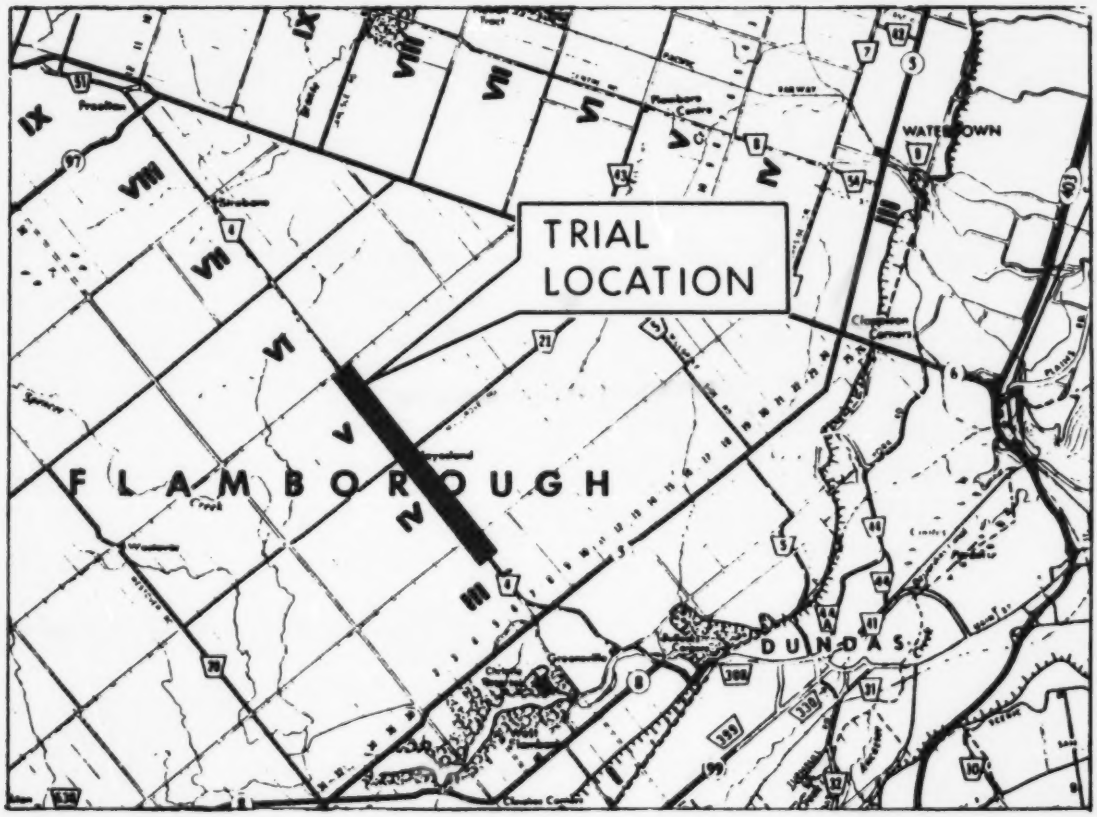
APPENDIX F: Field Test for Determining the Viscosity of Emulsified Asphalt Prior to Spraying 33

APPENDIX G: Skid Resistance Equipment 38

APPENDIX H: Sound Level Measurements 39

APPENDIX I: Measurement of Texture Depth by the Sand Patch Method 41





Trial Location - Region of Hamilton-Wentworth
Region Road No. 504

ABSTRACT

Surface treatments have been constructed for many years with good results on low volume roads in Ontario. There is a need, however, for a surface treatment system which will produce a long wearing surface with good friction properties which will withstand high traffic volumes.

A modified single surface treatment was placed in 1982 on Hamilton-Wentworth Regional Road 504. The surface treatment system consisted of one application of CRS-2 emulsified asphalt binder followed by two applications (coarse and fine) of steel slag aggregate. Standard surface treatment equipment was used with the addition of a second aggregate spreader and a vibratory roller specially designed for surface treatment work. For comparison purposes, a standard double surface treatment was constructed using the same materials, personnel and equipment.

The purpose of the trial was to develop a surface treatment system that could be used as an alternate to the current practice of resurfacing highways with hot mix asphaltic concrete. Also the new construction techniques, equipment and performance of the modified single surface treatment were assessed.

This report outlines the design, materials, construction, performance and costs of the modified single surface treatment system. It also contains comparisons of friction values, sound levels, texture depths and costs of double surface treatment, conventional and recycled hot mix resurfacing.

After more than two years of service this modified single surface treatment system:

1. Appears to be durable.

2. Has outstanding friction values.

3. Generates slightly higher sound levels than standard hot mix pavements.

4. Is similar to hot mix pavements in winter maintenance procedures if tungsten carbide snow plough blades are used.

5. Is equal to or better than the double surface treatment (with steel slag aggregates) in performance.

6. Is approximately 50% less expensive than 40 mm of hot mix resurfacing.

7. When used with a 25 mm levelling course is 30% more expensive than cold milling and 40 mm of recycled hot mix.

It is recommended that consideration be given to constructing a full scale project using this modified single surface treatment system with steel slag aggregates in lieu of hot mix resurfacing.

MODIFIED SINGLE SURFACE TREATMENT USING STEEL SLAG AGGREGATE

by D.F. Lynch, J.A. Cooper and R.C. Aquin

INTRODUCTION

The search for bituminous pavements that are economical, long wearing with good surface characteristics is never ending. European countries such as England, France and Sweden routinely place surface treatments over hot mix pavements to extend pavement life and to improve friction values. In Ontario, surface treatments are used solely on secondary highways and low traffic volume roads. A modified single surface treatment with high quality aggregates was placed in 1982 over hot mix pavement to determine if surface treatments were feasible in the Ontario climate and highway system. This report describes the materials, design, construction, performance and costs of a modified single surface treatment system.

BACKGROUND

Current Ministry practice is to confine surface treatment mainly to secondary highways with low (<1000 AADT) traffic volumes. Surface treatment is applied to existing primed surfaces, old surface treated roads and newly graded and primed roads depending on location, AADT and volume of truck traffic. Most surface treatments on secondary highways are constructed using high float asphalt emulsions (100S, 150S or 250S, depending on traffic volume) and Class 2 aggregate (crusher-run) with 100% passing the 16.0 mm sieve, 25-50% passing the 4.75 mm sieve and 0-5% passing the 75 um sieve. Emulsion quantities range from 1.20 to 1.55 kg/m^2 and aggregate quantities range from 16.5 to 19.0 kg/m^2. The Ministry is well satisfied with the performance of this type of surface treatment constructed on secondary highways using these materials.

Occasionally washed Class 1 aggregates are used for surface treatments when available from commercial sources. Surface treatments with Class 1 aggregates have a better appearance but are more expensive than surface treatments with Class 2 aggregates. The available Class 1 aggregates (9.5 to 6.7 mm in size) are predominantly limestone which wears and polishes when subjected to higher traffic volumes. There is also some penetration of the Class 1 aggregate into the underlying pavement further reducing frictional properties and increasing the incidence of flushing in the wheel tracks. The Ministry is not considering expanding the use of Class 1 aggregates for surface treatment, but will continue its use on a limited basis on the rural highways.

The need is evident for a surface treatment system (over an existing hot mix pavement) that will retain good frictional values under heavy traffic conditions.

Description of Previous Trial

With the above background, it was decided in 1980 to construct a trial section of surface treatment over a hot mix pavement using a larger aggregate, 10-13 mm in size[1]. The purpose of this trial was to determine if the larger aggregate could be successfully placed and would indeed result in a high quality surface treatment. The trial was carried out on Highway 121 in July 1980. The existing pavement was an HL-4 hot mix constructed in 1974, with a 1983 traffic count of 1000 AADT. On the basis of inspections over 4 years, it was observed that this surface treatment has performed very well. The larger aggregate, as anticipated, has produced a more open textured surface than normally obtained using Class 1 aggregate. It was also noted after the first winter that snow ploughs had done minor damage by shearing some of the aggregate from the high spots on the road.

Description of Modified Single Surface Treatment Trial

Based on the success with the initial trial, a second trial was arranged in 1982 using a modified single surface treatment system similar to that used in Sweden and France. This system consists of spraying one application of emulsified asphalt followed by two applications of aggregate. The first application is 12-16 mm aggregate and the second application is 4-8 mm aggregate. The 4 mm gap (12-8) between aggregate sizes is desirable for best results. Both aggregate applications are spread before rolling. Compaction is carried out using a vibratory roller equipped with a 25 mm thickness of rubber vulcanized onto the vibrating steel drum. This roller is especially manufactured for surface treatment work to vibrate the aggregate quickly into place without crushing, providing good aggregate orientation and improved asphalt bonding to the aggregate. The possibility of loose aggregate (whip off) which would inconvenience the travelling public is greatly reduced.

(1) Surface treatment with 10-13 mm aggregate, MTC Materials Information No. 29, by R.C. Aquin.

FIGURE 1: REGIONAL ROAD NO. 504
BEFORE SURFACE TREATMENT

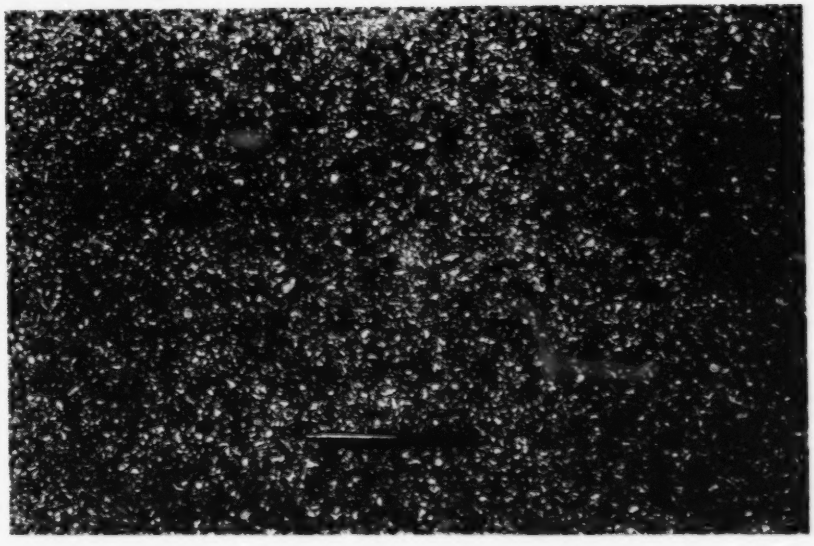


FIGURE 2: CLOSE-UP OF THE HOT MIX SURFACE
BEFORE SURFACE TREATMENT

Trial Location

The trial (3.22 km in length) was constructed on Regional Road No. 504 in the Region of Hamilton-Wentworth. Prior to 1976, Road No. 504 had been a surface treated surface. Because of increased traffic volume, the road was surfaced with a levelling course of HL-2 and a wearing course of 63 mm of HL-3 in the summer of 1976. The HL-3 pavement was in good condition in 1982 with a minimum amount of cracking and was smooth and slightly porous. The riding quality was excellent and the wheel lane depressions were virtually non existent so that levelling was not required. The road required only minor spray patching along the edges in isolated locations to treat edge cracking prior to constructing the trial surface treatment. The road is classified as Class A and the 1983 AADT was 2450±, with approximately 10 to 20% commercial vehicles.

Control Trials

Immediately south of the modified single surface treatment (MSST) on Regional Road No. 504, a standard double surface treatment (DST), 1.15 km in length, was constructed. The existing HL-3 pavement conditions were the same as for the MSST. The same CRS-2 emulsified asphalt and steel slag aggregates were used with two applications of CRS-2 emulsion and two applications of aggregate (one coarse and one fine).

On nearby Regional Road No. 21, a standard single surface treatment using CRS-1 emulsion and Class 1 limestone aggregates was constructed by the Region over an existing surface treatment. The two control trials provided an opportunity to compare the performance of the MSST, the DST and a typical single surface treatment.

MATERIALS

Aggregate

Steel slag was selected for the trial because of its desirable physical characteristics and was readily available. Steel slag was expected to provide a longer wearing surface with excellent frictional characteristics due to its harsh macrotexture. The aggregate was obtained from Steetley Industries Ltd. in Dundas, Ontario, who have provided steel slag aggregate to the Ministry for use in Open and Dense Friction Courses and HL-1 hot mix asphaltic concrete since 1977. Steetley Industries purchase raw open-hearth and basic oxygen furnace steel slag from Stelco Industries in Hamilton and process it at their quarry in Dundas.

On the basis of information obtained from Sweden, the Ministry requested Steetley Industries to produce two sizes of aggregate, namely 4-8 mm and 12-16 mm. with a 4 mm gap, for the trial. Processing consisted of washing and screening the raw slag in order to obtain material as close as possible to the desired gradation. The composition of the raw slag and the screen sizes used actually produced aggregates within the 4-9 mm and 12-19 mm ranges (larger than requested), with a gap of only 3 mm. Eighty percent of the 4-9 mm aggregate had a median size of 5.5 mm and ninety-three percent of the 12-19 mm aggregate had a median size of 13mm. The median size of the smaller aggregate was 42% of the larger aggregate and considered acceptable since it has been observed that the most desirable surface texture is attained when the median size of the smaller aggregate is approximately 50% of the larger aggregate. The median size is obtained by drawing a line vertically upward to the millimetre (mm) scale from the intersection of the gradation line and the 50% passing line (see Figure A-1 in Appendix A). For gradations of the aggregates and physical test results see Appendix A.

FIGURE 3: STEEL SLAG, 12-19 mm

FIGURE 4: STEEL SLAG, 4-9 mm

Asphalt Binder

Laboratory curing and bonding tests and small (30 x 30 cm) field trials were conducted with RS-2, CRS-2 and HF-100S emulsified asphalts to determine the most suitable binder. The laboratory tests are described in Appendix B and field trials are described in Appendix C.

CRS-2 was chosen for its faster curing and better bonding properties which would allow traffic to be restored as quickly as possible after construction thus minimizing the disruption to the travelling public. It was also selected on the basis of having a higher viscosity to minimize the possibility of run-off when spraying the larger-than-usual amount of binder required by the system. The CRS-2 was obtained from T.J. Pounder Ltd., Brampton, Ontario, who had the contract to supply the Region of Hamilton-Wentworth with their annual emulsion requirements. For CRS-2 laboratory test results, see Appendix D.

Application Rates

Typical application rates which have been used successfully in Sweden under similar conditions are as follows:

Emulsified Asphalt	-	2.15 kg/m^2
12-16 mm Aggregate	-	20.5 kg/m^2
4-8 mm Aggregate	-	7.0 kg/m^2

For the laboratory trials, based on the porosity and absorptive properties of the steel slag and a comparison of the density of steel slag vs. limestone and an assessment of the pavement condition and traffic volume, it was decided that the most desirable laboratory application rates for emulsion and aggregate would be:

Emulsified Asphalt	-	2.50 kg/m^2
12-19 mm Aggregate	-	22.0 kg/m^2
4-9 mm Aggregate	-	9.0 kg/m^2

These rates were confirmed by field test results shown in Appendix C.

CONSTRUCTION

The work was carried out by the Region of Hamilton-Wentworth personnel and equipment with the addition of the vibratory roller and a second aggregate spreader. The Region has been constructing all of its own surface treatment work for many years and enjoys an excellent reputation for high quality work, which is evident from the results achieved on this trial.

Prior to commencement of the work on Region Road No. 504, a small test area 100 m in length was constructed on Regional Road No. 21 adjoining Road No. 504. The purpose of this test was to familiarize Regional personnel with the system, which departs from normal surface treatment practice since only one application of emulsion is sprayed with two applications of aggregate being spread before rolling. It provided an opportunity to calibrate the pressure distributors and aggregate spreaders as well as check the proposed design quantities and provided the roller operator with an opportunity to familiarize himself with the operation of the new vibratory roller.

On the basis of the results of this small test area, the desired application rates were revised as follows:

Emulsified Asphalt	-	2.55 kg/m^2
12-19 mm Aggregate	-	21.5 kg/m^2
4-9 mm Aggregate	-	10.5 kg/m^2

Equipment

The following equipment was used to construct the work:

2 - Etnyre 1000 gallon capacity pressure distributors,

2 - Self-propelled Flaherty aggregate spreaders,

1 - Dynapac vibratory CA-25 10.0 tonne, with a 25 mm rubber pad vulcanized to the steel drum,

1 - Bros 9 wheel self-propelled 8.0 tonne pneumatic-tired roller,

1 - power broom,

7 - dump trucks.

Procedure, Modified Single Surface Treatment

The day prior to the start of the work, the pavement was swept clean with a power broom. The work started on August 25, 1982 at 10:45 a.m. The weather was ideal, with low humidity and bright and sunny conditions with a temperature of 22°C and northwest winds at 30-50 km/h.

The work proceeded as follows:

(1) The emulsion was sprayed at a temperature of 65°C.

(2) The 12-19 mm aggregate was spread immediately after the emulsion had been sprayed so that the distance between the pressure distributor and the aggregate spreader was at no time greater than 30 m.

(3) The 4-9 mm aggregate was then spread on top of the 12-19 mm so that the distance between the two aggregate spreaders was at no time greater than 15 m.

(4) The aggregates were then immediately rolled with the Dynapac vibratory roller, followed by the rubber-tired roller with a minimum of two passes with each roller.

Spraying of the emulsion, spreading of the two aggregates and rolling were all carried out with no problems and the work was done at a very productive rate.

The application rates of all materials were checked during the work using 50 cm square cardboard trays and a portable battery operated digital read out scale, as well as by totalling quantities used and calculating the area covered (see Appendix E). The actual average application rates for the 3.22 km completed were as follows:

Emulsified Asphalt	-	2.60 kg/m^2
12-19 mm Aggregate	-	20.6 kg/m^2
4-9 mm Aggregate	-	9.1 kg/m^2

FIGURE 5: SPRAYING BINDER

FIGURE 6: SPREADING 12-19 mm AGGREGATE

FIGURE 7: SPREADING 4-9 mm AGGREGATE

FIGURE 8: VIBRATORY ROLLER

FIGURE 9: RUBBER-TIRED ROLLER

FIGURE 10: MODIFIED SINGLE SURFACE TREATMENT

FIGURE 11: CLOSE-UP OF MODIFIED
SINGLE SURFACE TREATMENT

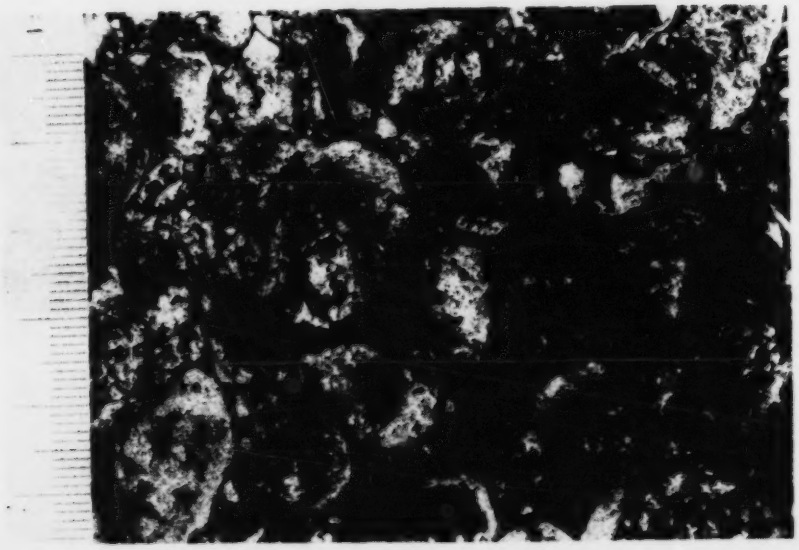


FIGURE 12: CLOSE-UP OF MODIFIED
SINGLE SURFACE TREATMENT

Field sampling to determine the viscosity of the emulsion just prior to spraying was carried out using the Zahn cup as described in Appendix F, with test results shown in Table F-2.

Procedure, Double Surface Treatment

For comparison purposes, adjoining the south end of the trial of the modified surface treatment previously described, a double surface treatment was constructed, 1.15 km in length, using the same emulsion (CRS-2) and steel slag aggregates (12-19 mm and 4-9 mm). This work was also carried out on August 26, 1982 using the same personnel, equipment and techniques under the same weather conditions.

The actual average application rates were as follows:

1st Application of Emulsified Asphalt	-	1.80 kg/m^2
Application of 12-19 mm Aggregate	-	20.5 kg/m^2
2nd Application of Emulsified Asphalt	-	1.52 kg/m^2
Application of 4-9 mm Aggregate	-	16.5 kg/m^2

Traffic Control

Road No. 504 was closed off to through traffic during construction and only local traffic was allowed. Traffic control was removed about 4:00 pm when work was completed. The MSST and the DST were immediately opened to evening traffic. The decision to close the road was made by the Region as a matter of convenience only. Traffic over both the modified single surface treatment and the double surface treatment could easily have been controlled in the normal manner using convoy trucks with the appropriate signs.

Rotary Power Brooming

Both surface treatments on Regional Road No. 504 were swept with a power sweeper (street cleaner) on the following day, August 27th, to remove loose aggregate. The three intersections were swept 11 days after construction. The entire road was swept a second time on September 20, approximately three weeks later.

COSTS

Modified Single Surface Treatment

The total cost per km for this modified surface treatment system in 1982 was as follows:

Actual Material Costs		
Emulsified Asphalt 17,483 kg @ $0.22	= $3,846.26	
Steel Slag Aggregate 202 tonnes @ $16.75	= 3,383.50	$ 7,230.
***Estimated Application Costs**		
Applying Emulsified Asphalt 17,483 kg @ $0.056	= 979.05	
Applying Steel Slag Aggregate 202 tonnes @ $10.00	= 2,020.00	2,999.
Total Cost per km		$10,229.

*The actual application costs incurred by the Region might not have been representative of tendered costs for this work. Therefore, the application costs shown are based on current industry tendered costs for 1982, including allowances for supplying the additional chip spreader and the vibratory roller.

Double Surface Treatment

Total cost per km for this double surface treatment was as follows:

Actual Material Costs		
Emulsified Asphalt 22,244 kg @ $0.22	= $4,893.68	
Steel Slag Aggregate 248 tonnes @ $16.75	= 4,154.00	$ 9,048.
Estimated Application Costs		
Applying Emulsified Asphalt 22,244 kg @ $0.056	= 1,245.66	
Applying Steel Slag Aggregate 248 tonnes @ $10.00	= 2,480.00	3,726.
Total Cost per km		$12,774.

COST COMPARISON SURFACE TREATMENT VS. HOT MIX

The cost of modified single surface treatment (MSST), 6.7 m wide, was $10,229/km in 1982. The MSST cost, 7.3 m wide, was estimated at $12,303/km in 1984 by adding 5% per annum for 1983 and 1984.

The average cost of hot mix resurfacing, 7.3 m wide in 1984 was estimated to be $26,305./km. This was based on:

HL-4 (40 mm)	729 t	
Asphalt cement (5.3%)	39 t	
Granular 'A' shouldering	383 t	
For a total cost of		$ 26,305/km

The anticipated cost saving per km by replacing hot mix with MSST was $14,000.

HL-4 (40 mm)	-	$ 26,305/km
Modified single surface treatment	-	12,303/km
Anticipated cost saving		$ 14,002/km

The average cost of cold milling and paving with a single lift of recycled hot mix, 7.3 m wide, was estimated to be $21,610/km in 1984. This was based on:

Cold milling (25 mm)	450 t	
Recycle hot mix, 50/50, (40 mm)	729 t	
Asphalt cement (2.7%)	20 t	
Granular 'A' shouldering	144 t	
For a cost of		$ 21,610/km

The cost of MSST plus an HL-2 levelling course, 7.3 m wide, was estimated to be $28,250/km in 1984. This was based on:

Modified single surface treatment	-	$ 12,303/km
HL-2 (25 mm)	416 t	
Asphalt cement (6.0%)	25 t	
Granular 'A' shouldering	234 t	
For a cost of		$ 28,250/km

Summary

The average estimated cost of the various options, 7.3 m wide, in 1984 was:

- Modified single surface treatment (MSST) $ 12,303/km
- Cold Milling (25 mm) plus recycled hot mix, 50/50,(40 mm) $ 21,610/km
- HL-4 resurfacing (40 mm) $ 26,305/km
- MSST plus a levelling course of HL-2 (25 mm) $ 28,250/km

COMPARISON OF PAVEMENT SURFACE CHARACTERISTICS

The location of the trial of the modified single surface treatment process with steel slag on Regional Road No. 504 provided a unique opportunity to directly compare this work with the existing HL-3 pavement, with a double surface treatment with steel slag, with a normal single surface treatment constructed with CRS-1 emulsion and Class 1 limestone aggregate on adjoining Regional Road No. 21, and with an HL-1 pavement on King's Hwy.#5 using steel slag coarse aggregate.

Skid Resistance

Skid measurements were taken using the Ontario Ministry of Transportation and Communications brake-force trailer conforming to ASTM Standard E-274 (Refer to Appendix G). The modified single surface treatment provided the excellent skid values when compared with other pavement types. Results of the tests conducted at 80 km/h are shown in Table A.

Sound Levels

Sound level measurements were taken by using a special testing trailer equipped with a microphone positioned 10 cm behind the tire and 10 cm above the road. The trailer is towed over the pavement at 80 km/h and the sound levels are measured in dBA (Leq). The sound levels were measured in 1982 and in 1984 for four of the pavement types: modified single surface treatment (MSST), double surface treatment (DST), HL-3 surface course, all on Regional Road No. 504 and standard single surface treatment on Regional Road No. 21.

The sound level measurements in Table B, show a 1 dBA drop over 2 years for the MSST and the DST on Regional Road No. 504. The HL-3 surface course on Regional Road No. 504 is virtually unchanged over the same 2 year period. A 1.7 dBA decrease was recorded for the standard single surface treatment on Regional Road No. 21 over the two year period. The three types of surface treatments shown in Table B generate sound levels of 101.2 to 102.2 dBA while the HL-3 surface course generates 98.6 dBA, a difference of approximately 3 dBA.

Sound level measurements recorded in 1982 and 1983 by locating sound metres 15 m from the centreline of the roads are found in Table H-1 of Appendix H.

TABLE A: SKID RESISTANCE TEST RESULTS

PAVEMENT TYPE	SN 80 km/h (Range)			
	1982	1983	1984	1985
Modified Single Surface Treatment with Steel Slag (R.R. No. 504)	48.6	45.0	44.9	44.5
Double Surface Treatment with Steel Slag (R.R. No. 504)	46.9	40.9	42.7	44.8
HL-3 Surface Course with Limestone Coarse Aggregate (R.R. No. 504)	25.9	24.3	35.1	36.6
Standard Single Surface Treatment with Limestone Aggregate, 9 mm (R.R. No. 21)	45.8	37.8	33.4	34.1
HL-1 Surface Course with Steel Slag Coarse Aggregate (King's Hwy. #5)	34.2	35.5	39.1	38.5

TABLE B: SOUND LEVEL FIELD MEASUREMENTS

Pavement Type	Sound Level, dBA (Leq)		Difference (1982 - 1984) dBA (Leq)
	1982	1984	
Modified Single Surface Treatment with Steel Slag (R.R. No. 504)	102.8	101.8	1.0
Double Surface Treatment with Steel Slag (R.R. No. 504)	103.1	102.2	0.9
HL-3 Surface Course with Limestone Coarse Aggregate (R.R. No. 504)	98.7	98.6	0.1
Standard Single Surface Treatment with Limestone Aggregate, 9 mm (R.R. No. 21)	102.9	101.2	1.7

Texture Depth

Surface texture measurements were taken using the sand patch method described in Appendix I (reference ASTM STP-763). Results of these tests are summarized in Table C.

TABLE C: TEXTURE DEPTH MEASUREMENTS

Pavement Type	Depth, mm		
	1982	1983	1984
Modified Single Surface Treatment with Steel Slag (R.R. No. 504 AADT 2450±)	4.43	2.64	1.69
Double Surface Treatment with Steel Slag (R.R. No. 504 AADT 2450±)	3.25	2.56	1.46
HL-3 Surface Course with Limestone Coarse Aggregate (R.R. No. 504 AADT 2450±)	0.67	0.54	0.49
Standard Single Surface Treatment with Limestone Aggregate, 9 mm (R.R. No. 21 AADT 490±)	3.26	2.61	1.74

The results in Table C show that there is major difference in surface texture between roads surface treated with steel slag vs. hot mix. This difference in texture is primarily responsible for the increase in sound level and skid resistance provided by the steel slag surface.

On high speed roads it has been found necessary to maintain a minimum texture depth of 0.65 mm to ensure that the decrease in skid resistance with speed is not unduly large.

The maintenance of surface texture depth on surface treated roads depends on traffic volume, the relative hardness of the old road surface, which will effect the embedment of the aggregate under traffic, and the wear of the aggregate. These factors can therefore have a marked effect on the performance of surface treatments and will directly effect not only surface texture but also sound level and skid resistance. The steel slag surface treatments have maintained more than adequate texture depth after 2 years of service.

PERFORMANCE

The modified single surface treatment (MSST) on Regional Road No. 504 is performing well after 28 months in service. All the qualities of a good surface treatment are evident over the 3.2 km length: uniform appearance, correct asphalt binder level (texture depth), absence of aggregate loss, absence of bleeding and good skid resistance.

The standard double surface treatment (DST) placed immediately south of the MSST is in good condition. Visually, the DST has a finer surface texture than the MSST. There is slight flushing in the wheel tracks of the southbound lane caused by loaded trucks hauling out of a limestone quarry. The flushing is not present in the northbound lane or in either lanes north of the quarry, because most of the loaded trucks from the quarry travel south.

On Regional Road No.21, the standard single surface generally is in good condition with the correct binder level and the absence of aggregate loss. There are many short sections about 10 metres in length near centreline that are depressed (rutted) and are flushed. The flushed sections may be a result of excess binder placed in past surface treatments and armour coats (penetration macadam). Some spray patching was done in 1984 along the outer edges to correct the breakage of the surface treatment.

Comparing Performance of Modified Single Surface Treatments with Double Surface Treatment

The DST has a finer surface texture than the MSST as the texture depth measurements show: 1.69 mm (MSST) and 1.46 mm (DST). The texture depth may account for the slightly higher skid resistance numbers for the MSST, 44.9 for the MSST and 42.7 for the DST. The sound levels from the DST are slightly higher than those from the MSST. Neither surface treatments exhibit aggregate loss after 28 months in service. The binder level is satisfactory for both surface treatments except for the southbound lane of the DST where trucks are hauling from the limestone quarry. Overall the MSST is performing better than the DST.

Winter Maintenance

The steel slag surface treatments are similar to the HL-3 pavement in blowing snow, slushy snow and icy conditions. Both pavement types are ploughed and salted in the same manner according to Mr. L. Bisbee of the Region of Hamilton-Wentworth.

The Region experienced difficulties with snowplough blades in the first winter, 1982-83, and part of the second winter. The hard, abrasive steel slag aggregate wore the standard plough blades out after three or four passes. Near the end of 1983-84 winter, the Region purchased a tungsten carbide plough blade and mounted it in front of the standard blade. Special Ni-Hard shoes were also mounted, two on the plough blade and three on the wing. This system appears to be performing satisfactorily.

Safety

The Region of Hamilton-Wentworth supplied accident information. The number of accidents occurring on the surface treated sections (both MSST and DST) of Regional Road No. 504 has declined since 1982. Refer to Table D.

TABLE D: FREQUENCY OF ACCIDENTS ON THE SURFACE TREATED SECTIONS OF REGIONAL ROAD NO. 504

1980	1981	1982(1)	1983	1984
13	12	9	3	7

NOTE 1: The modified Single Surface Treatment and Double Surface Treatment were constructed in August, 1982.

Comments from Property Owners

Four property owners living within 15 m of the edge of pavement were interviewed in November 1984. When asked about increased sound levels from the slag surface treatments, two out of the four noticed an increase, but stated that the noise increase did not bother them. One specifically remembered the noise increase and said it was annoying in the summertime when the windows were open. The fourth property owner did not notice the noise increase.

When asked about accidents on the steel slag surface treatments, three could not recall any accidents. The fourth thought that there were fewer minor accidents at the intersection of Regional Road No. 504 and Concession 5 since the MSST was placed.

CONCLUSIONS

1. This modified single surface treatment system can be constructed using standard surface treatment equipment and methods with the addition of the vibratory roller.

2. This system performs well.

3. This system provides excellent friction characteristics.

4. This system generates higher sound levels (approximately 3 dBA) than standard hot mix pavements.

5. This system is similar to hot mix pavements in winter performance and maintenance procedures, however, tungsten carbide snowplough blades are required.

6. This system is equal to or better than the double surface treatment (with steel slag aggregates) in performance.

7. This system is approximately 50% less expensive than 40 mm of hot mix resurfacing, however the system plus a 25 mm levelling course is 30% more expensive than the cold milling and 40mm of recycled hot mix.

RECOMMENDATIONS

1. Consideration should be given to constructing a full scale project using this modified single surface treatment system with steel slag.

2. Consideration should be given to using this system for correcting bleeding or flushed hot mix pavements and in black spot treatment.

3. In order to reduce sound levels and provide a slightly tighter surface texture without reducing frictional characteristics or service life, it is recommended that the steel slag aggregate should be produced at nominal sizes of 12-16 mm and 4-8 mm.

4. Work should be carried out to identify improved binders such as polymer modified binders so that traffic can be restored quicker after construction with the long term benefit of better aggregate retention.

5. The option of cold milling with MSST should be investigated by setting up a small project. There is some doubt that the surface texture left by cold milling may not be suitable for placing the modified single surface treatment, but this has not been proven.

ACKNOWLEDGEMENTS

A special thanks to Mr. R. Fraser, Maintenance Engineer, Region of Hamilton-Wentworth, and to all the members of his office and field staff who made such a valuable contribution to this trial. The splendid co-operation provided by Mr. J. Marcolin and Mr. H. Donnelly of the Hamilton District Office, Mr. R.W. Pipe and Mr. J.L. MacDonald of Steetley Industries, Mr. E. McKillen of Dynapac Ltd., and Mr. M. Kavanaugh of T.J. Pounder Ltd. is much appreciated.

APPENDIX A - AGGREGATE GRADINGS AND PHYSICAL TEST RESULTS

TABLE A-1: 4-9 and 12-19 mm STEEL SLAG GRADINGS

MTC Sieve mm	Percentage Passing	
	4-9 mm	12-19 mm
19.0	-	100.00
16.0	-	96.3
13.2	-	63.4
9.5	100.0	4.0
6.7	68.4	2.6
4.75	20.6	2.3
2.36	2.3	-
1.18	1.7	-
0.60	1.3	-
0.30	1.0	-
0.15	0.7	-
0.075	0.3[1]	1.0[1]

1. Wash pass 75 um sieve, MTC LS-601 Test Method

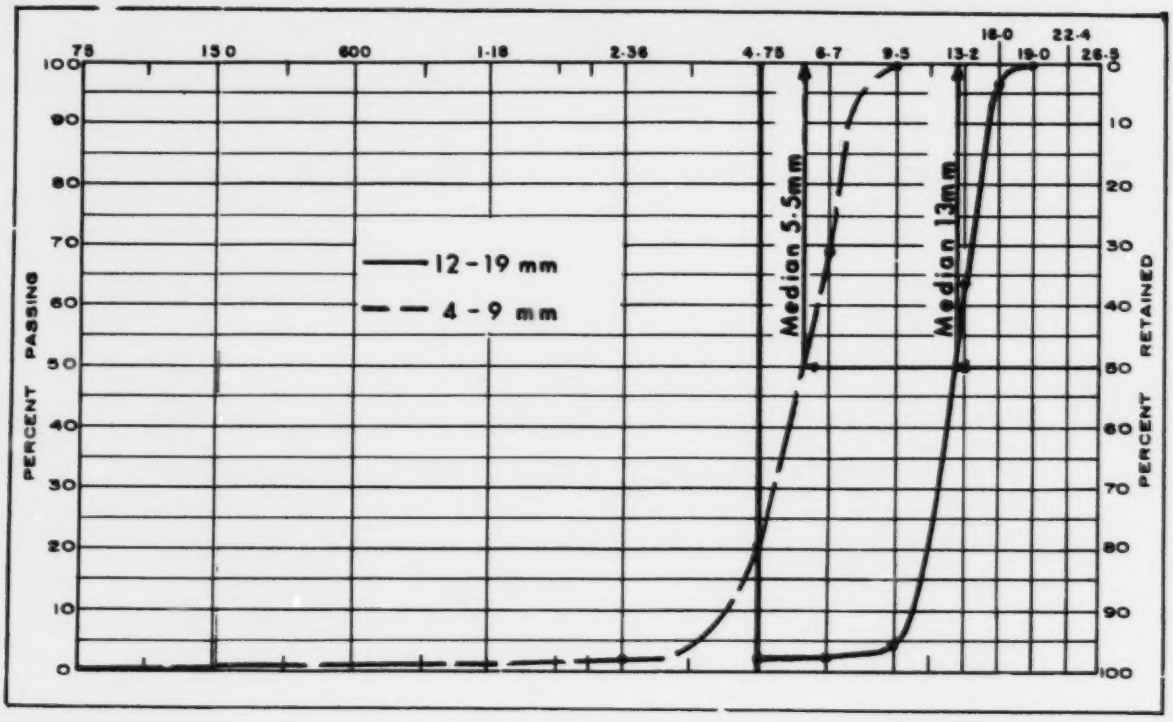
TABLE A-2: PHYSICAL TEST RESULTS, STEEL SLAG

Test	4-9 mm	12-19 mm
Los Angeles Abrasion Loss, %	24.64	23.70
Absorption, %	1.819	1.235
Non-Slag Material, %	9.5	3.8
Aggregate Abrasion Value (AAV)[1]	-	3.8
Polished Stone Value (PSV)[2]	58.5	60.0
Relative Density	3.406	3.555
Density, Loose, t/m^3	1.635	1.625

1. British Standard BS 812, 1975.
   The resistance of aggregate particles to wear is measured by the AAV test. A low value indicates a high resistance to wear. A typical limestone has a AAV range 8-30.

2. British Standard BS 812, 1975.
   An aggregate with a high PSV may be thought of as having good (skid) resistance to the action of polishing by vehicle tires. The higher the PSV the better the aggregate. A typical limestone has a PSV range of 30-50.

FIGURE A-1: 4-9 and 12-19 mm STEEL SLAG AGGREGATE GRADINGS



APPENDIX B - LABORATORY PROCEDURE FOR SELECTING THE MOST SUITABLE TYPE AND GRADE OF EMULSIFIED ASPHALT FOR A GIVEN AGGREGATE FOR SURFACE TREATMENT

Procedure

(1) Calculate the weight in grams of aggregate and emulsion required for a 22.8 cm x 33.0 cm pan based on the design quantities.
(Design quantities in grams per square metre ÷ 13.28).

(2) Weigh calculated weight (1) of dried aggregate at 25°C into a metal container.

(3) Add 2% moisture by mass of cold tap water to the aggregate.
Mix thoroughly and let stand one hour.

(4) Heat the emulsion to 70°C and pour the desired amount evenly into the pan.

(5) Sprinkle onto the hot emulsion, the required amount of aggregate, as evenly as possible.

(6) Immediately roll the aggregate three times in the longitudinal direction with a steel roller 2.6 cm in width and 5.1 cm in diameter and weighing 1.8 kg. Roll with moderate hand pressure.

(7) Test for curing at room temperature, every 15 minutes. Use a 2.5 cm spatula to pick apart about a 5.1 cm square area of the sample. Note the colour of the emulsion, percent cured, and the bond strength of the aggregate to the emulsion.

(8) Continue to inspect until the sample is 100% cured and a firm bond is obtained.

This test should be carried out with anionic, cationic and high float emulsion to select the most suitable emulsion for the aggregate.

Interpretation of Results

The emulsion with the fastest curing time and the best bond should be selected for the aggregate.

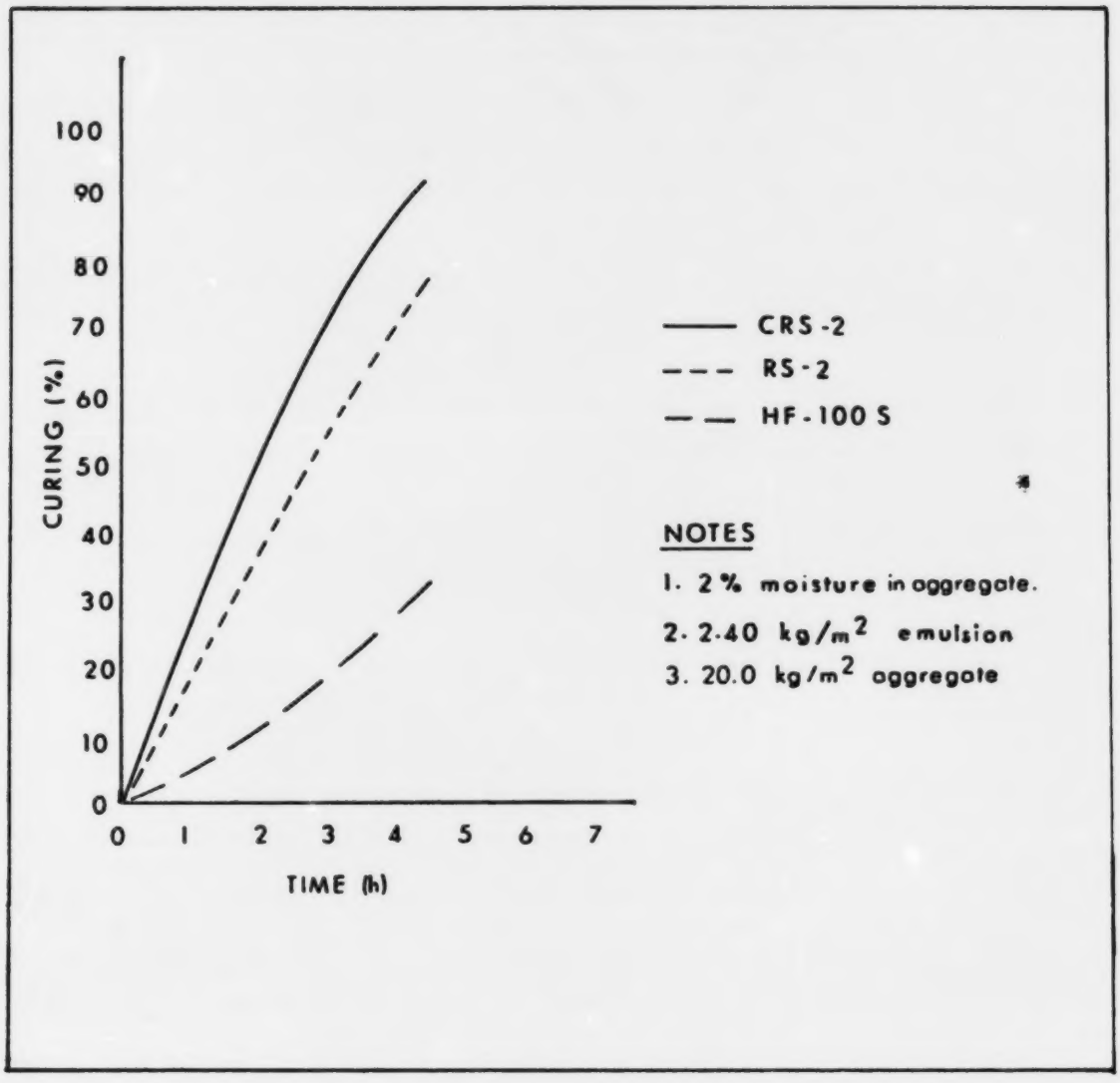


FIGURE B-1: CURING TESTS WITH 12-19 mm STEEL SLAG

APPENDIX C - FIELD TESTS TO CONFIRM EMULSION-SLAG COMPATIBILITY

Test Patches with Steel Slag

Six test patches with emulsion and steel slag were placed in the MTC Parking Lot "C" on 82-06-09, and application rates of the patches are shown below. The purposes of the tests were to:

(1) determine approximate application rates of emulsion and aggregate.

(2) determine the most suitable emulsion to use with steel slag.

(3) observe performance over a two-month period.

Aggregates

Two gradations of steel slag were used:

4-9 mm, and 12-19 mm

Tap water at 2% was added to the 4-9 and 12-19 mm aggregate.

Procedure

(1) Aggregates were weighed and water was added.

(2) Emulsions were weighed into beakers.

(3) Test site was swept clean with a broom.

(4) Emulsion was poured onto pavement into a template 30.5 cm x 30.5 cm square and spread with a spatula.

(5) Aggregate was immediately spread from a pan.

(6) Aggregate was rolled immediately with six complete coverages of a car tire.

(7) Traffic was kept off patches for 18 hours.

Weather

25°C, sunny, light breeze

APPLICATION RATES

Modified Single Surface Treatment

2.50 kg/m^2

12-19 mm @ 22.0 kg/m^2

4-9 mm @ 9.0 kg/m^2

3 patches 30.5 x 30.5 cm with CRS-2, RS-2 and HF-100S

Double Surface Treatment

1.80 kg/m^2

12-19 mm @ 21.0 kg/m^2

1.45 kg/m^2

4-9 mm @ 9.0 kg/m^2

3 patches 30.5 x 30.5 cm with CRS-2, RS-2 and HF-100S

Observations During Tests

1. The CRS-2 emulsion broke very quickly. The RS-2 was the second fastest breaking emulsion. The HF-100S was the slowest breaking. Patches with the HF-100S were still tender after four hours.

2. The application rates of aggregate were reasonably correct.

3. The CRS-2 emulsion was very viscous, followed by the RS-2 and the HF-100S.

4. Where HF-100S was used as binder, there was pick-up while rolling.

5. The method of applying emulsion (pouring emulsion from a beaker), for the second application on the conventional double was not satisfactory. The emulsion could not be uniformly spread.

6. On patches of double surface treatment, all loose 12-19 mm aggregate was removed before applying second application of binder and 4-9 mm chips.

7. Compactive effort was not sufficient to key all the 4-9 mm aggregate into the binder in any of the patches.

Results of the test patches confirmed that the most suitable emulsion for the trial was CRS-2.

APPENDIX D - CRS-2 LABORATORY TEST RESULTS

TABLE D-1: CRS-2 LABORATORY TEST RESULTS

Test	CRS-2	MTC Requirements Min.	Max.
Visc. at 50°C, S.F.s	102.2	100	400
Residue	71.1	67	-
Residue Penetration	182	100	250
Residue Duct. at 25°C	60+	60	-
Settlement, 5 Days, %	1.1	-	5
Sieve Test, %	0.06	-	0.10
Demulsibility, %	41.5	40	-
Particle Charge	Positive	Positive	
Oil Portion, %	0.6	-	3

APPENDIX E - FIELD SAMPLING TO DETERMINE THE AMOUNT OF BINDER AND AGGREGATE APPLIED TO A ROAD

Equipment

(1) 1 - Battery operated digital scale, 10 kg capacity, with a stainless steel platform approximately 30 cm x 40 cm.

(2) A supply of cardboard trays 50 cm x 50 cm with a 2.5 cm lip.

(3) Pocket calculator.

(4) Carpenter's level.

(5) Gloves.

(6) Mineral spirits.

(7) Rags.

Procedure

(1) Set up and level digital scale.

(2) Number the cardboard trays.

(3) Obtain the tare weight in kilograms of two 50 x 50 cm cardboard trays and record.

(4) Place the two cardboard trays in the centre of the lane being treated approximately two feet apart and parallel to the centreline of the road, immediately prior to the area being teated.

(5) Remove the first tray after the binder has been sprayed and before the aggregate has been applied.

(6) Remove the second tray after the binder has been sprayed and the aggregate has been applied and before rolling.

(7) Obtain the gross weight in kilograms of the first tray.

(8) Obtain the net weight in kilograms of binder applied in the first tray.

Net Weight = Gross Weight - Tare Weight

(9) Calculate the amount of binder applied to the road as follows:

Net Weight (8) x 4 = _ _ _ kg/m2

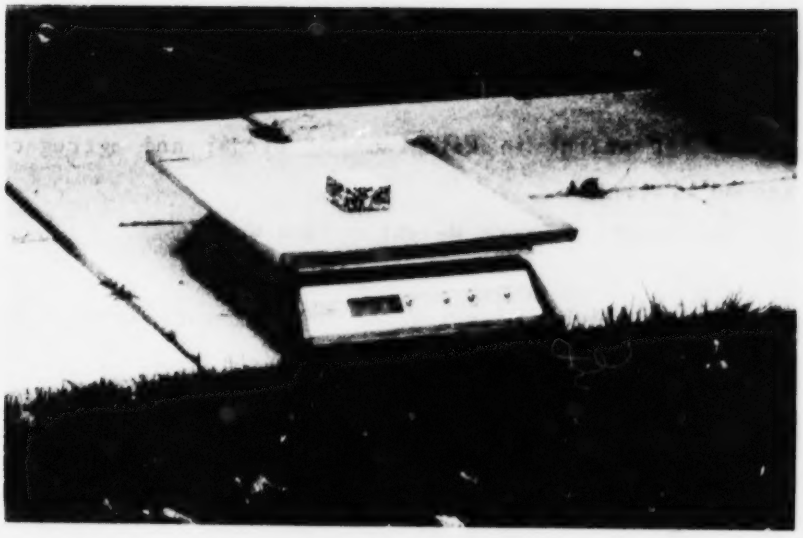


FIGURE E-1: WEIGHING TRAY

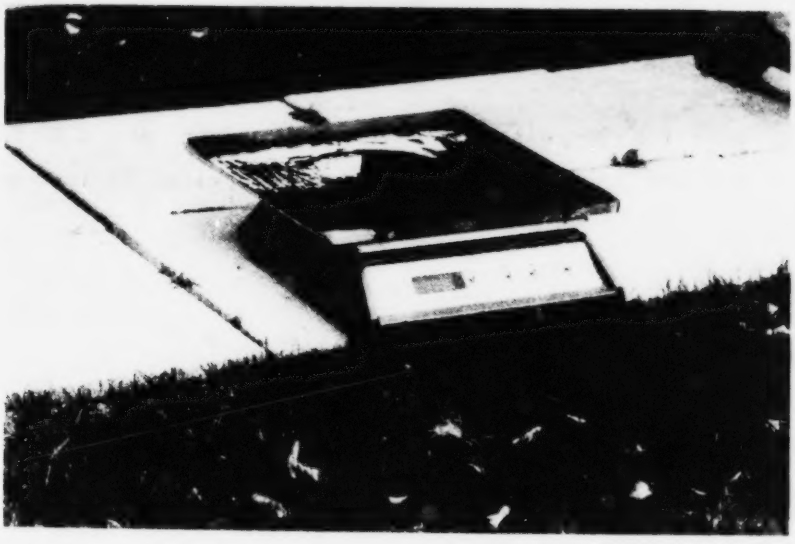


FIGURE E-2: WEIGHING TRAY AND BINDER

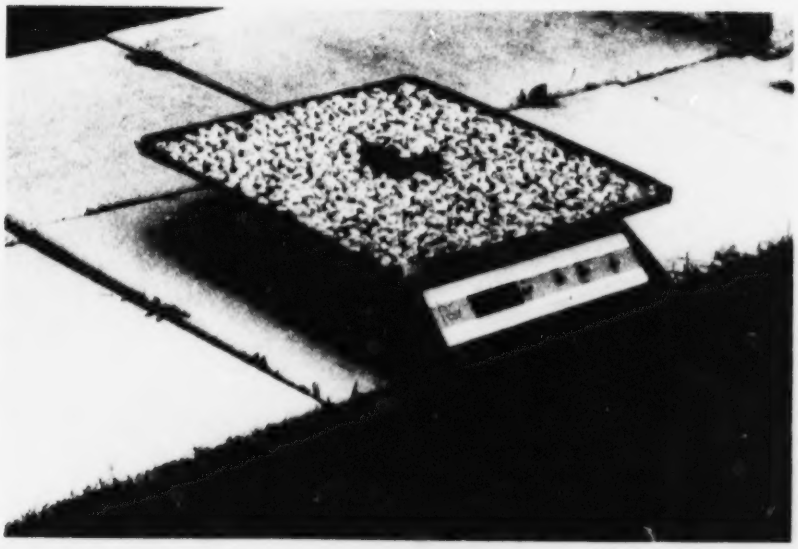


FIGURE E-3: WEIGHING TRAY, BINDER AND 12-19 mm AGGREGATE

(10) Obtain the gross weight in kilograms of the second tray.

(11) Obtain the net weight in kilograms of binder and aggregate applied in the second tray.

Net Weight = Gross Weight - Tare Weight

(12) Obtain the net weight in kilograms of aggregate applied in the second tray.

Net Weight of Aggregate

= Net Weight of second tray (11)

- Net Weight of first tray (8)

(13) Calculate the amount of aggregate applied to the road as follows:

Net Weight of Aggregate (12) x 4

= ___ kg/m^2

(14) Repeat sampling process at least three times per 2.0 km lanes and adjust application rates if necessary to obtained desired quantities.

Maintenance

- recharge the batteries in the scale as required.

- clean scale platform with mineral spirits and rags after use.

APPENDIX F - FIELD TEST FOR DETERMINING THE VISCOSITY OF EMULSIFIED ASPHALT PRIOR TO SPRAYING

ZAHN VISCOSIMETER TEST FOR EMULSIFIED ASPHALT

Equipment

1. Zahn viscosimeter cup No. 3 (Figure F-1).
2. Stop watch.
3. Thermometer range 40°C-90°C.
4. Gallon sample cans.
5. Mineral spirits (varsol).
6. Rags.
7. Table 1 used to determine viscosity in Saybolt Furol seconds at 50°C for emulsified asphalt.

Procedure

1. Obtain emulsion sample in one gallon can.
2. Immediately take emulsion temperature and record.
3. Immerse Zahn cup into emulsion until the top of the cup is approximately 15 mm below emulsion surface. (Figure F-2).
4. Allow the cup to warm up (1-2 minutes).
5. Lift the cup until the rim of cup is just below the surface.
6. Lift the cup out of the emulsion and at the same time start the stop watch. (Figure F-3).
7. When the stream breaks, stop the stop watch. (Figure F-4).
8. Record the time in the nearest 1/10 second.
9. Repeat the procedure three times taking the average time to the nearest second.
10. Record the average viscosity in Saybolt Furol seconds at 50°C as determined using Table F-1.

NOTES: 1. The test must be performed within the temperature range 60°C to 80°C. If the sample is above 80°C, it should be allowed to cool to less than 80°C before testing. If the emulsion as delivered is below 60°C, a decision has to be made either to reject the material because of low temperature or to heat the material on site above the minimum of 60°C before sampling and testing. Do not attempt to heat the sample.

2. One Zahn test (average of three readings) is required for each tanker load of emulsion.

3. The sample taken for Zahn testing can be used as the field sample submitted for laboratory results.

4. Some judgement is necessary when stopping the time. The stream becomes narrow and then breaks. Stop the time when the stream first breaks.

TABLE F-1: FOR DETERMINING VISCOSITY IN SAYBOLT FUROL SECONDS AT 50°C FOR EMULSIFIED ASPHALT

Seconds for Flow Thru Zahn Cup No. 3 @ 60 to 80°C	Saybolt Furol Seconds @ 50°C	Seconds for Flow Thru Zahn Cup No. 3 @ 60 to 80°C	Saybolt Furol Seconds @ 50°C
5	12	31	90
6	15	32	93
7	18	33	96
8	21	34	99
9	24	35	102
10	27	36	105
11	30	37	108
12	33	38	112
13	36	39	115
14	39	40	118
15	42	41	121
16	45	42	124
17	48	43	127
18	51	44	130
19	54	45	133
20	57	46	136
21	60	47	139
22	63	48	142
23	66	49	145
24	69	50	148
25	72	51	151
26	75	52	154
27	78	53	157
28	81	54	160
29	84	55	163
30	87	56	166

TABLE F-2: VISCOSITY DETERMINED BY USING ZAHN CUP NO. 3

Sample No.	Temp. °C	Seconds for Flow Through Zahn Cup	Saybolt Furol Seconds @ 50°C
1	68	36	105
2	70	39	115
3	65	42	124

FIGURE F-1: ZAHN VISCOSIMETER
CUP NO. 3

FIGURE F-2: CUP IMMERSED
IN BINDER

FIGURE F-3: LIFTING CUP
OUT OF BINDER

FIGURE F-4: STREAM BREAKS
AND TIME STOPPED

APPENDIX G - SKID RESISTANCE EQUIPMENT

FIGURE G-1: SKID TRAILER AND TRUCK

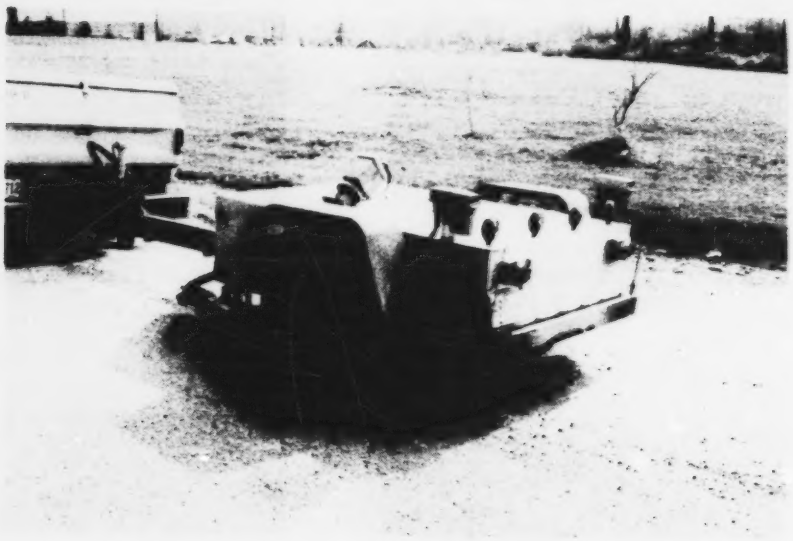


FIGURE G-2: SKID TRAILER

FIGURE G-3: PERFORMING SKID TEST

APPENDIX H - SOUND LEVEL MEASUREMENTS

Equipment

The following Equipment was used to conduct measurements:

Bruel & Kjaer Piston Phone Calibrator, Type 4220
Bruel & Kjaer Integrating Sound Level Meter, Type 2218
Bruel & Kjaer 30 m Extension Cable, Type AO 0029
Under 4200 Stereo Report Monitor Tape Recorder
BASF Recording Tape, Type DP 26, ferro LH, Hi Fi

Additional equipment required to analyze the results:

Bruel & Kjaer Noise Level Analyzer, Type 4426
Bruel & Kjaer Alphanumeric Printer, Type 2312
Bruel & Kjaer Level Recorder, Type 2306
Bruel & Kjaer Digital Frequency Analyzer, Type 2131
Hewlett Packard X-Y Recorder, Type 7035B

Procedure

In 1982 and 1983 sound levels were measured by placing two sound level meters at two adjacent pavement sections, 15 m from the roadway centreline. Sound level measurements at these two locations were done simultaneously by recording sound levels on a magnetic tape for later analysis in the laboratory.

TABLE H-1: SOUND LEVELS, REGIONAL ROAD NO. 504

Traffic Condition	Increase in Sound Levels Due to the Change from Typical Hot Mix HL-3 to Surface Treatment, Slag	
	1982	1983
Average operating speed of cars as well as trucks, 80-100 km/h, 10 to 20% of trucks	5 dBA[1]	
Cars only at 80 to 100 km/h	7 dBA[1]	
Average operating speed of cars 70-80 km/h, trucks 60-70 km/h, 10% medium trucks, 10% heavy trucks	2 dBA[2]	1 dBA[2,3]
Cars only at 70 to 80 km/h	5 dBA[2]	4.5 dBA[2,3]

1. Increase based on speed, traffic composition and previous experience.

2. Actually measured values at Regional Road No. 504.

3. The sound level difference of 1 dBA is considered the smallest perceivable difference.

4. Sound level meters placed 15 m from centreline of road.

APPENDIX I - MEASUREMENT OF TEXTURE DEPTH BY THE SAND PATCH METHOD

Reference

ASTM STP-763

Material

Ottawa Sand C-109

Apparatus

graduated cylinder, 250 mL
yellow crayon
broom
ruler, 40 cm
hard rubber disc, 7 cm diameter

Procedure

1. Remove loose material from the surface with broom.
2. Draw a circle approximately 40 cm in diameter.
3. Measure approximately 500 mL of sand, tapping the graduated cylinder lightly on the road three times before reading the volume.
4. Pour the sand into the centre of the circle.
5. Spread the sand with the rubber disc, starting in the centre and gradually working outward using circular motions, keeping the sand patch as circular as possible.
6. Measure the diameter of the sand patch in four places.

Calculation

$$TD = \frac{V}{r^2}$$

where TD = texture depth (mm)
V = volume (mL) of sand
r = radius (cm)

1. Determine the average diameter and radius.
2. Determine the TD.

Frequency

Every 0.5 km in the outside wheel passes.

Texture depth is the mean thickness of the layer of sand that fills the cavities and channels in the pavement surface if spread evenly on a smooth surface over a covered area.

Texture is the "roughness" that in a bituminous surface, is most significantly influenced by aggregate size. Texture generates resistance to sliding via the hysteresis effects in the tread rubber and facilitates the expulsion of water from the tire pavement interface.

The friction that develops between tire and pavement has two components, adhesion and hysteresis. (Adhesion is surface friction, hysteresis is deformation loss).

Microroughness (that roughness that is being diminished when the surface is being polished) influences the adhesion components most strongly. Macroroughness or texture (as given by the shape and arrangement of the aggregate particles embedded in the matrix of the pavement surface course) has a first-order effect on the hysteresis component.

The adhesion friction component on wet surface tends to decrease with speed, the hysteresis component gains in importance at higher speeds. Thus, texture is beneficial to the generation of friction, but its more important function is to provide channels by which water can escape from under the tire so that the tread rubber can make contact with the pavement.

Correlation of texture depth with skid resistance is not perfect, but adequate for many purposes.

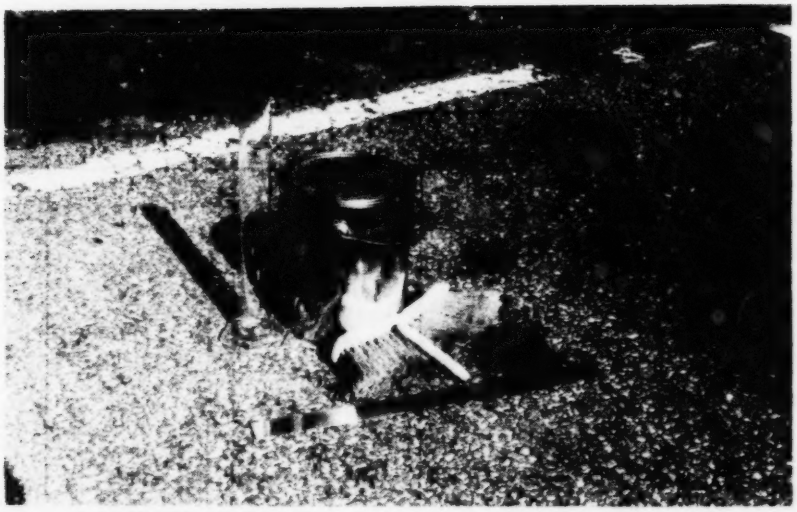


FIGURE I-1: SAND PATCH APPARATUS

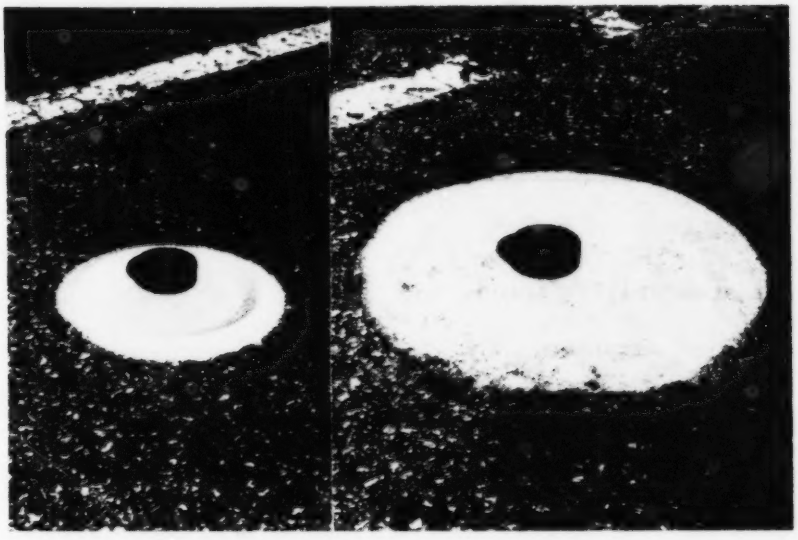


FIGURE I-2: SPREADING OTTAWA SAND

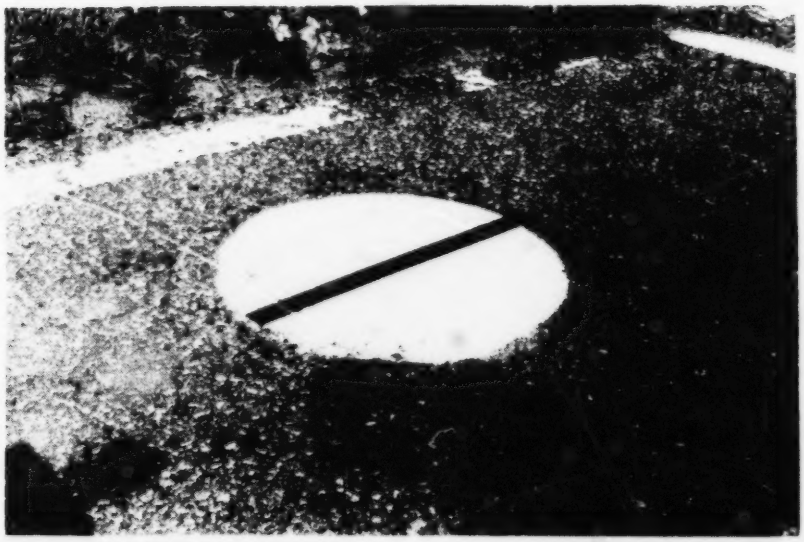


FIGURE I-3: MEASURING DIAMETER OF PATCH

TABLE I-1: TEXTURE DEPTH MEASUREMENTS

Pavement Type	Parameter	1982	1983	1984
Modified Single Surface Treatment with Steel Slag (R.R. No. 504)	$\bar{x}$ (mm)[1]	4.43	2.64	1.69
	s (mm)[2]	0.40	0.50	0.22
	n[3]	14	14	14
Double Surface Treatment with Steel Slag (R.R. No. 504)	$\bar{x}$ (mm)	3.25	2.56	1.46
	s (mm)	0.12	0.21	0.13
	n	6	6	6
HL-3 Surface Course with Limestone Coarse Aggregate (R.R. No. 504)	$\bar{x}$ (mm)	0.67	0.54	0.49
	s (mm)	-	0.03	0.03
	n	1	4	4
Standard Single Surface Treatment with Limestone Aggregate, 9 mm (R.R. No. 21)	$\bar{x}$ (mm)	3.26	2.61	1.74
	s (mm)	0.28	0.24	0.23
	n	2	4	4

1. $\bar{x}$, Test mean.

2. s, Test standard deviation.

3. n, Number of samples.

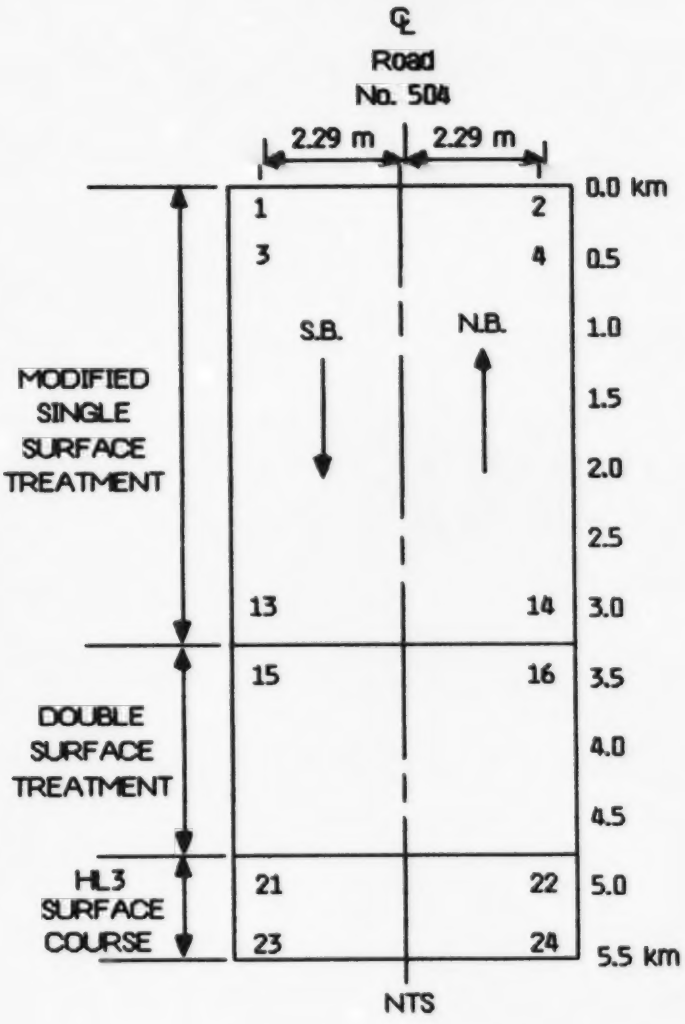


FIGURE I-4: TEXTURE DEPTH MEASUREMENT LOCATIONS, REGIONAL ROAD NO. 504

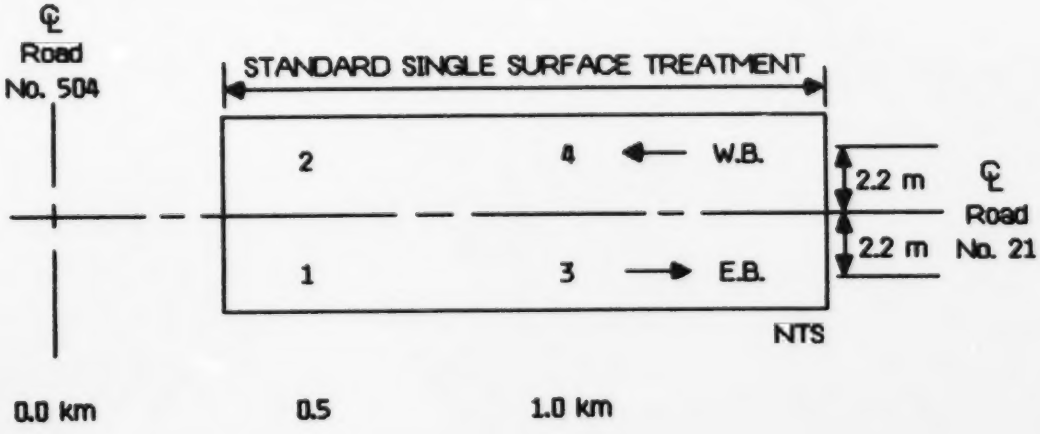


FIGURE I-5: TEXTURE DEPTH MEASUREMENT LOCATIONS, REGIONAL ROAD NO. 21